

U.S. DEPARTMENT OF COMMERCE, PATENT AND TRADEMARK OFFICE

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DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

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TITLE OF INVENTION
CONTROLLABLE MAGNETIC BEARING APPARATUS AND METHOD FOR DETERMINING A MACHINE TYPE OF A MAGNETIC BEARING

APPLICANT(S) FOR DO/EO/US - Hirochika Ueyama

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a FIRST submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a SECOND or SUBSEQUENT submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This express request to begin national examination procedures (35 U.S.C. 371(f) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(I).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371(c)(2))
 - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau)
 - b. ☒ has been transmitted by the International Bureau (see Form 308) c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☒ A translation of the International Application into English (35 U.S.C. 371(c)(2))
7. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371(c)(3))
 - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau)
 - b. ☐ have been transmitted by the International Bureau.
 - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
 - d. ☐ have not been made and will not be made.
8. ☒ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
9. ☒ An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. ☒ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11. to 16. below concern other document(s) or information included:

11. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98. (w/ copy of PTO-1449 and each reference cited therein and Int'l Search Rept)
12. ☒ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. ☐ A FIRST preliminary amendment.
☐ A SECOND or SUBSEQUENT preliminary amendment.
14. ☐ A substitute specification.
15. ☐ A change of power of attorney and/or address letter.
16. ☒ Other items or information:

- a) PCT Form PCT/IB/308
- b) PCT Request (PCT/RO/101) (In Japanese)
- c) Copy of cover page of International Application WO 01/06139 (PCT/JP00/04781) with International Search Report (PCT/ISA/210)
- d) Notification of Receipt of Record Copy (Form PCT/IB/301)
- e) Notification Concerning Submission of Transmittal of Priority Document (PCT/IB/304)



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PATENT TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371U.S. APPLICATION NO. (if known,
see 37 CFR 1.5)17. ☒ The following fees are submitted:

CALCULATION

PTO USE ONLY

Basic National Fee (37 CFR 1.492(a)(1)-(5)):

Search Report has been prepared by the EPO or JPO \$860.00
International preliminary examination fee paid to USPTO (37 CFR 1.482) \$670.00
No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee
paid to USPTO (37 CFR 1.445(a)(2)) \$760.00
Neither international preliminary examination fee (37 CFR 1.482) nor
international search fee (37 CFR 1.445(a)(2)) paid to USPTO \$970.00
International preliminary examination fee paid to USPTO (37 CFR 1.482)
and all claims satisfied provisions of PCT Article 33(2)-(4) \$96.00

ENTER APPROPRIATE BASIC FEE AMOUNT =

\$860.00

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☐ 30 months from the earliest
claimed priority date (37 CFR 1.495(e)).

\$ -

Claims

Number Filed

Number Extra

Rate

Total Claims 3 - 20 = 0 x \$18.00 \$ -

Independent Claims 3 - 3 = 0 x \$80.00 \$ -

Multiple dependent claim(s) (if applicable)

+ \$260.00

\$ -

TOTAL OF ABOVE CALCULATIONS =

\$ 860.00

Reduction by 1/2 for filing by small entity, if applicable. Verified Small Entity statement must also be filed.
(Note 37 CFR 1.9, 1.27, 1.28).

\$ 0.00

SUBTOTAL =

\$ 860.00

Processing fee of \$130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest
claimed priority date (37 CFR 1.492(f)).

\$ -

TOTAL NATIONAL FEE =

\$ 860.00

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an
appropriate cover sheet (37 CFR 3.28, 3.31). \$40.00 per property.

\$ 40.00

TOTAL FEES ENCLOSED =

\$ 900.00

Amount to be
refunded \$

charged \$

- a. ☒ A check in the amount of \$ 900.00 to cover the above fees is enclosed.
b. ☐ Please charge my Deposit Account No. 02-4300 in the amount of \$ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.
c. ☒ The Commissioner is hereby authorized to charge any additional fees which may be required with respect to any deficiency in the above noted
"Basic National Fee", or credit any overpayment to Deposit Account No. 02-4300.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed
and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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REGISTRATION NO.

Date: March 2, 2001

DESCRIPTION

Controllable magnetic bearing apparatus and
method for determining a machine type
of a magnetic bearing

5

TECHNICAL FIELD

The present invention relates to a controllable
magnetic bearing apparatus and a method for determining
a machine type of a magnetic bearing.

10

BACKGROUND ART

15

The controllable magnetic bearing apparatus
consists of a machine body including a rolling element
and magnetic bearings, and a control unit for controlling
the machine body. There are plural types of machine
bodies so that control parameters vary depending upon
the machine types. Accordingly, there has been a need
for providing each control unit in correspondence to
each type of machine body.

20

In order to provide each control unit in
correspondence to each type of machine body, multiple
types of control units must be fabricated on a small-lot
basis. This not only imposes inconvenience but also
makes it impossible to reduce costs through mass
production.

25

In view of the foregoing, the present invention has an object to provide a controllable magnetic bearing apparatus having a control unit applicable to multiple types of machine bodies. It is another object of the present invention to provide a method for determining a machine type to apply the control unit to any of the multiple types of machine bodies.

DISCLOSURE OF THE INVENTION

In accordance with the present invention, a controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprises: means for moving the rolling element in a stationary state in a predetermined direction to determine an amount of movement thereof to a movement limit; and means for determining a machine type of the magnetic bearing based on the amount of movement and setting control parameters (Claim 1).

In the controllable magnetic bearing apparatus thus arranged, the amount of movement of the rolling element is determined by moving the rolling element in a stationary state to the movement limit. The machine type is determined based on a fact that the amount of movement varies depending upon the machine types and

then, the setting of control parameters is made. Accordingly, a common control unit can be applied to the multiple types of machine bodies.

In accordance with the present invention, a
5 controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprises: means for moving the rolling element in a stationary state in plural directions to
10 determine respective amounts of movement of the rolling element to respective movement limits; means for determining a mean amount of movement based on the amounts of movement; and means for determining a machine type of the magnetic bearing based on the mean amount
15 of movement and setting control parameters (Claim 2).

In the controllable magnetic bearing apparatus thus arranged, determined is the mean amount of movement of the rolling element when the rolling element in a stationary state is moved to the movement limits in the
20 plural directions. Subsequently, the machine type is determined based on a fact that the mean amount of movement varies with each machine type, so as to set the control parameters. Accordingly, a common control unit can be applied to multiple types of machine bodies.
25 In addition, the determination of the machine type is

highly reliable because the determination is based on the mean amount of movement.

In accordance with the present invention, a method for determining a machine type of a magnetic bearing comprises: the steps of moving a rolling element supported by a magnetic bearing from a rest position to place on one side of a first radial axis for determining an amount of movement thereof to a movement limit; then moving the rolling element to place on one side of a second radial axis for determining an amount of movement thereof to a movement limit; then moving the rolling element to place on the other side of the first radial axis for determining an amount of movement thereof to a movement limit; then moving the rolling element to place on the other side of the second radial axis for determining an amount of movement thereof to a movement limit; operating a mean amount of movement based on the amounts of movement; and determining a machine type of the magnetic bearing based on the mean amount of movement and setting control parameters (Claim 3).

In the method for determining the machine type of the magnetic bearing, the mean amount of movement is found from the amounts of movement of the rolling element, which, initially being in a stationary state, is sequentially moved to each of the movement limits in

each of the different directions. The machine type is determined based on the fact that the mean amount of movement varies with each machine type. Then, the setting of control parameters is made. Accordingly, a common control unit can be applied to multiple types of machine bodies. The determination of the machine types is highly reliable because the determination is based on the mean amount of movement.

10 BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a flow chart showing a method of machine type determination taken by a controllable magnetic bearing apparatus according to one embodiment of the present invention;

15 FIG.2 is a plan view showing the positional relationship between an inside-diameter circle of a protective bearing and a rolling element movable in a range inscribed by the circle;

FIG.3 is a diagram showing the rolling element of
20 FIG.2 internally touching a +Y side of the inside-diameter circle;

FIG.4 is a diagram showing the rolling element of
FIG.2 internally touching a +X side of the inside-diameter circle;

25 FIG.5 is a diagram showing the rolling element of

FIG.2 internally touching a -Y side of the inside-diameter circle;

FIG.6 is a diagram showing the rolling element of FIG.2 internally touching a -X side of the
5 inside-diameter circle;

FIG.7 is a diagram showing each position of the center of and each amount of movement of the rolling element when the rolling element is sequentially moved to each of movement limits thereof;

10 FIG.8 is a diagram showing each position of the center of and each amount of movement of the rolling element when the rolling element is sequentially moved to each of movement limits thereof, in a case where an initial position of the center of the rolling element
15 is out of the origin of the X-Y coordinates;

FIG.9 is a vertical sectional view showing a machine body of the controllable magnetic bearing apparatus;

FIG.10 is a horizontal sectional view showing the
20 above machine body;

FIG.11 is a block circuit diagram of the above controllable magnetic bearing apparatus;

FIG.12 is a block diagram showing only a portion of the arrangement of the controllable magnetic bearing
25 apparatus that is involved in the control of radial

position; and

FIG.13 is a block diagram showing only a portion of the arrangement of the controllable magnetic bearing apparatus that is involved in the control of axial position.

BEST MODES FOR CARRYING OUT THE INVENTION

FIG.9 is a vertical sectional view showing a machine body 1 of a controllable magnetic bearing apparatus according to one embodiment of the present invention, and FIG.10 is a horizontal sectional view thereof.

The machine body 1 is of a vertical construction wherein a rolling element 3 in the form of a vertical shaft rotates within a cylindrical casing 2. In the following description, an axial direction of the rolling element 3 is defined as Z direction and respective directions orthogonal to the Z direction, as seen in the figure, are defined as X direction and Y direction.

Besides the casing 2 and rolling element 3, the machine body 1 further includes an axial magnetic bearing 4, a radial magnetic bearing 5, an axial displacement sensor 6, a radial displacement sensor 7, a motor 8, and a protective bearing 9.

The axial magnetic bearings 4 are disposed above

and below a flanged portion 3a of the rolling element 3 as sandwiching the flanged portion therebetween, thereby axially supporting the rolling element 3 in a noncontact fashion. The radial magnetic bearings 5 are disposed at two places on Z-axis thus forming two groups, each of which consists of four radial magnetic bearings equally spaced by 90° around the rolling element 3. The radial displacement sensors 7 are disposed at the same circumferential positions as the radial magnetic bearings 5 in close adjacency thereto along the Z direction, thus forming two groups of four. The axial displacement sensor 6 is disposed opposite to an axial end portion 3b of the rolling element 3. The motor 8 is mounted to an inside wall of the casing 2 for rotating the rolling element 3 at high speeds. The protective bearings 9 are arranged in paired relation for limiting movable ranges of the rolling element 3 with respect to the axial and radial directions, as well as for providing contact support for the rolling element 3 in case the magnetic noncontact support for the rolling element 3 may be disabled. A radial clearance and an axial clearance between the protective bearing 9 and the rolling element 3 are of given values determined according to the type of the machine body 1.

FIG.11 is a block circuit diagram showing

connection between the machine body 1 of the above arrangement and a control unit 11 forming, in combination with the machine body, the controllable magnetic bearing apparatus.

5 The control unit 11 includes a sensor circuit 12, a magnetic-bearing drive circuit 13, an inverter 14, a DSP board 15 and a serial communication board 21. The DSP board 15 is provided with a DSP 16 as a digital signal processor, a ROM 17 connected thereto, a flash memory 10 18 as a nonvolatile storage device, an A/D converter 19 and a D/A converter 20.

A personal computer 22 disposed at place remote from the control unit 11 is connected to the serial communications board 21 of the control unit 11.

15 Output signals from the axial displacement sensor 6 and radial displacement sensors 7 are inputted to the DSP 16 via the sensor circuit 12 and A/D converter 19. On the other hand, the DSP 16 provides control of the axial magnetic bearings 4 and radial magnetic bearings 20 5 via the D/A converter 20 and magnetic-bearing drive circuit 13, thereby allowing the rolling element 3 to be supported in the noncontact fashion as controlling the position of the rolling element 3. The DSP 16 also controls the rotation of the motor 8 via the inverter 25 14.

The ROM 17 stores a processing program and the like to be performed in the DSP 16. The flash memory 18 stores data which include plural sets of control parameters corresponding to the plural types of machine bodies 1, mean movement spans S (to be described hereinlater in detail) corresponding to the plural types of machine bodies 1, a bias current value I_0 to be described hereinlater and the like. These data items can be rewritten through the personal computer 22.

FIG.12 is a block diagram showing only a portion of the arrangement of the control unit 11 that is involved in the control of radial position. It is assumed that the pair of radial displacement sensors 7 shown in the figure are, for example, disposed opposite to each other across the rolling element 3 along X-axis. The outputs from these radial displacement sensors 7 are inputted to the sensor circuit 12 in which a processing is performed to subtract one of the outputs from the other. An output from the sensor circuit 12 is A/D converted for giving a displacement signal ΔX . The signal indicates a displacement of the rolling element 3 from a target position with respect to X-axis. The DSP 16 outputs two exciting current signals $(I_0 + I_c)$ and $(I_0 - I_c)$ based on the displacement signal ΔX . I_0 means herein a bias current value, and I_c means a control current

value depending upon the sign and magnitude of ΔX . The exciting current signals $(I_o + I_c)$ and $(I_o - I_c)$ are each D/A converted and then amplified by an amplifier 13a in the magnetic-bearing drive circuit 13. The amplified signals are supplied to the pair of radial magnetic bearings 5 opposing each other across the rolling element 3 along X-axis. According to the displacement signal ΔX , adjustment is made to the electromagnetic force with respect to a direction in which the displacement is reduced to 0. As a result, the rolling element 3 is supported at the X-axis target position.

A similar positional control is performed on Y-axis.

FIG.13 is a block diagram showing only a portion of the arrangement of the control unit 11 that is involved in the control of axial position. An output from the axial displacement sensor 6 is inputted to the sensor circuit 12. Based on the output signal from the axial displacement sensor 6, the sensor circuit 12 determines a displacement of the rolling element 3 with respect to a Z-axis target position. This displacement is A/D converted to a displacement signal ΔZ which is inputted to the DSP 16. The DSP 16 outputs two exciting current signals $(I_o + I_c)$ and $(I_o - I_c)$ based on the displacement

signal ΔZ . I_0 means herein a bias current value, and I_c means a control current value depending upon the sign and magnitude of ΔZ . The exciting current signals $(I_0 + I_c)$ and $(I_0 - I_c)$ are each D/A converted and then
5 amplified by the amplifier 13a in the magnetic-bearing drive circuit 13. The amplified signals are supplied to the axial magnetic bearings 4 disposed above and below the flanged portion 3a of the rolling element 3. Based on the displacement signal ΔZ , adjustment is made to
10 the electromagnetic force with respect to a direction in which the displacement is reduced to 0. As a result, the rolling element 3 is supported at the Z-axis target position.

The controllable magnetic bearing apparatus of the
15 above arrangement constitutes means for performing the rotation control and the positional control of the rolling element 3. Furthermore, the controllable magnetic bearing apparatus also constitutes: means which, at the start of operation, uses a positional
20 control function centralized on the DSP 16 to move the rolling element 3 in a stationary state in a predetermined direction for determining an amount of movement thereof to a movement limit; and means which determines the machine type of magnetic bearing (machine
25 body 1) based on the determined amount of movement for

setting control parameters. An operation for determining the machine type will hereinbelow be described in detail.

In the above controllable magnetic bearing apparatus, the axial magnetic bearing 4, radial magnetic bearing 5 and motor 8 are not driven when the control unit 11 is not powered up. Therefore, the rolling element 3 is at rest as supported by the protective bearings 9 in contact fashion. Upon power-up of the control unit 11, the DSP 16 identifies the machine body 1 according to a flow chart of FIG.1. The embodiment assumes that there are three types of machine bodies 1 which include Type-A, Type-B and Type-C. The length of the clearance between the rolling element 3 and the protective bearing 9 varies with each machine type.

First in Step S1, the DSP 16 takes measurement of the amount of movement to the movement limit. Specifically, the DSP reads provisional control parameters from the flash memory 18 to drive the axial magnetic bearings 4. This allows the rolling element 3 to be magnetically levitated to a provisional target position on Z-axis. In this state, the rolling element 3 is allowed to move in the radial direction within the range defined by the inside-diameter circle of the protective bearing 9.

FIG.2 to FIG.6 are diagrams illustrating in plan the positional relationship between an inside-diameter circle C of the protective bearing 9 and the rolling element 3 movable within an inscribed range of the circle.

5 First assume as an initial state that the rolling element 3 is positioned concentrically with the inside-diameter circle C, as shown in FIG.2. In this state, the DSP 16 stores a displacement signal $\Delta Y0 (=0)$ based on outputs from the radial displacement sensors 7 disposed in the +Y and -Y directions. Subsequently, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the +Y direction to thereby attract the rolling element 3 in the +Y direction. This brings the rolling element 3 into internal contact with the +Y side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.3). In this state, the DSP 16 reads a displacement signal $\Delta Y1$ based on outputs from the radial displacement sensors 7 disposed in the +Y and -Y directions. The DSP 16 calculates a difference (20 $(\Delta Y1 - \Delta Y0)$ between the displacement signal $\Delta Y1$ and the previously stored displacement signal $\Delta Y0$. Additionally, the DSP 16 determines an amount YLp (of positive sign) of movement of the rolling element 3 moved in the +Y direction from the position of FIG.2 to that (25 of FIG.3 using a previously inputted corresponding

relationship between the displacement signal and the actual displacement, and then stores the amount of movement thus determined. Furthermore, the DSP 16 stores a displacement signal $\Delta X_0 (=0)$ based on outputs from the radial displacement sensors 7 disposed in the +X and -X directions.

Next, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the +X direction to thereby attract the rolling element 3 in the +X direction. This brings the rolling element 3 into internal contact with the +X side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.4). In this state, the DSP 16 reads a displacement signal ΔX_1 based on outputs from the radial displacement sensors 7 disposed in the +X and -X directions. The DSP 16 calculates a difference ($\Delta X_1 - \Delta X_0$) between the displacement signal ΔX_1 and the previously stored displacement signal ΔX_0 . Based on the calculation result, the DSP 16 determines an amount XL_p (of positive sign) of movement of the rolling element 3 moved in the +X direction from the position of FIG.3 to that of FIG.4, then storing the amount of movement thus determined.

Next, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the -Y direction to thereby attract the rolling element 3

in the -Y direction. This brings the rolling element 3 into internal contact with the -Y side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.5). In this state, the DSP 16 reads a displacement signal $\Delta Y2$ based on outputs from the radial displacement sensors 7 disposed in the +Y and -Y directions. The DSP 16 calculates a difference ($\Delta Y2 - \Delta Y0$) between the displacement signal $\Delta Y2$ and the previously stored displacement signal $\Delta Y0$. Based on the calculation result, the DSP 16 determines an amount YLn (of negative sign) of movement of the rolling element 3 moved in the -Y direction from the position of FIG.2 to that of FIG.5, then storing the amount of movement thus determined.

Next, the DSP 16 supplies a predetermined exciting current only to the radial magnetic bearing 5 in the -X direction to thereby attract the rolling element 3 in the -X direction. This brings the rolling element 3 into internal contact with the -X side of the protective bearing 9 (the inside-diameter circle C) (a state of FIG.6). In this state, the DSP 16 reads a displacement signal $\Delta X2$ based on outputs from the radial displacement sensors 7 disposed in the +X and -X directions. The DSP 16 calculates a difference ($\Delta X2 - \Delta X0$) between the displacement signal $\Delta X2$ and the previously stored displacement signal $\Delta X0$. Based on the calculation

result, the DSP 16 determines an amount XL_n (of negative sign) of movement of the rolling element 3 moved in the -X direction from the position of FIG.3 to that of FIG.6, then storing the amount of movement thus determined.

5 FIG.7 is a plot of positions P_0 , P_1 , P_2 , P_3 and P_4 of the center of the rolling element 3 moved from the state of FIG.2 in the aforementioned manner or in the order of FIG.3, FIG.4, FIG.5 and FIG.6 as maintained in internal contact with the protective bearing 9. It is noted that the aforementioned amounts of movement YL_p , XL_p , YL_n , and XL_n are such lengths as shown in FIG.7.

10 It is noted that the initial position P_0 of the center of the rolling element 3 is not always at the center of P_1 to P_4 , as shown in FIG.8. In this case, YL_p and YL_n are not equal to each other because they are read with reference to the displacement signal ΔY_0 with respect to P_0 . Even in this case, however, the center of the rolling element 3 is moved to the position of P_1 when the rolling element 3 is attracted by the radial magnetic bearing 5 in the +Y direction. Accordingly, the amounts of movement, XL_p and XL_n are the same as in the case shown in FIG.7.

20 Based on the amounts of movement, YL_p , XL_p , YL_n and XL_n thus determined, the DSP 16 calculates a mean

25

value of movement span S (Step S2). Specifically, movement spans Ys and Xs in the Y and X directions are first determined using:

$$Ys = YLp - YLn$$

5 $Xs = XLp - XLn$

Next, the mean value of movement span S is determined using:

$$S = (Ys + Xs) / 2 \dots (1)$$

10 The reliability of the determination of the machine type (described later) is enhanced by determining the mean value S with respect to both the X and Y directions.

Subsequently, the DSP 16 determines whether or not the mean value of movement span S satisfies:

$$Slmin \leq S \leq Slmax \dots (2)$$

15 where Slmin and Slmax denote a minimum value and a maximum value of the radial clearance between the protective bearing 9 and the rolling element 3 in the machine body 1 of Type-A (Step S3). If the machine body 1 is Type-A, the answer to the above expression (2) is YES. Therefore,

20 the DSP 16 proceeds to Step S7 to read in control parameters for Type-A from the flash memory 18 and to set, based on the read control parameters, target values of support for the axial magnetic bearings 4 and the radial magnetic bearings 5.

25 If the machine body 1 is not Type-A, then the answer

to the above expression (2) is NO. Therefore, the DSP 16 proceeds to Step S4 to determine whether or not the mean value of the movement span S satisfies:

$$S_{2min} \leq S \leq S_{2max} \dots (3)$$

5 where S_{2min} and S_{2max} denote a minimum value and a maximum value of the radial clearance between the protective bearing 9 and the rolling element 3 in the machine body 1 of Type-B (provided that $S_{1max} < S_{2min}$). If the machine body 1 is Type-B, the answer to the above expression
10 (3) is YES. Therefore, the DSP 16 proceeds to Step S8 to read in control parameters for Type-B from the flash memory 18 and to set, based on the control parameters, target values of support for the axial magnetic bearings 4 and the radial magnetic bearings 5.

15 If the machine body 1 is not Type-B, the answer to the above expression (3) is NO. Therefore, the DSP 16 proceeds to Step S5 to determine whether or not the mean value of the movement span S satisfies:

$$S_{3min} \leq S \leq S_{3max} \dots (4)$$

20 where S_{3min} and S_{3max} denote a minimum value and a maximum value of the radial clearance between the protective bearing 9 and the rolling element 3 in the machine body 1 of Type-C (provided that $S_{2max} < S_{3min}$). If the machine body 1 is Type-C, the answer to the above expression
25 (4) is YES. Therefore, the DSP 16 proceeds to Step S9

to read in control parameters for Type-C from the flash memory 18 and to set, based on the control parameters, target values of support for the axial magnetic bearings 4 and the radial magnetic bearings 5.

5 If the machine body 1 is not Type-C, the answer to the above expression (4) is NO. Accordingly, the machine body 1 is not any of Type-A, Type-B and Type-C, so that the determination of machine type cannot be made. Therefore, the DSP 16 proceeds to Step S6 to indicate
10 abnormality.

 In this manner, the type of machine body 1 can be determined from the mean value of the movement spans S, and thereby the setting of control parameters for an applicable machine type is automatically made for
15 quickly transferring the rolling element to a magnetically levitated state. Thus, the common control unit 11 makes it possible to automatically set appropriate control parameters for any of the plural types of machine bodies 1 and to control the position
20 of the rolling element 3. This permits the control unit 11 to be applied to general purposes, so that the control unit 11 can be mass-produced for achieving the cost reduction. It is noted that abnormality is indicated only when the automatic determination is impossible and
25 then an operator sets the control parameters based on

his determination.

Although the flow chart (FIG.1) of the foregoing embodiment illustrates the processing for selecting any one of the three types, it is also possible to make
5 determination as to the larger number of machine types for automatic setting of the control parameters.

Although the foregoing embodiment determines the machine type based on the amounts of movement YLp , XLp , YLn and XLn , it is also possible to determine the machine
10 type based on only the amount of movement in the Y direction or X direction.

In the foregoing embodiment, prior to the determination of the amounts of movement YLp , XLp , YLn and XLn , the axial magnetic bearings 4 are excited to
15 effect a provisional state where the rolling element is levitated in the axial direction. However, the rolling element 3 may not be axially levitated if the rolling element 3 can be axially attracted even in a state where the rolling element is in contact with the
20 protective bearings 9.

In the foregoing embodiment, the determination of the machine type is made based on the amount of movement to the movement limit in the radial direction. However, it is also possible to determine the machine type based
25 on the amount of movement to the movement limit in the

axial direction. In this case, the rolling element 3 in a stationary state is levitated to bring its axial end portion 3a into abutment against the protective bearing 9 so that an amount of movement may be determined from an amount of variation of the displacement signal ΔZ from the axial displacement sensor 6 and then the machine type is determined based on this amount of movement.

CLAIMS

1. A controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprising:

means for moving said rolling element in a stationary state in a predetermined direction to determine an amount of movement thereof to a movement limit; and

means for determining a machine type of the magnetic bearing based on said amount of movement and setting control parameters.

2. A controllable magnetic bearing apparatus sensing a position of a rolling element supported by a magnetic bearing and controlling the position thereof, the apparatus comprising:

means for moving said rolling element in a stationary state in plural directions to determine respective amounts of movement thereof to respective movement limits;

means for determining a mean amount of movement based on said amounts of movement; and

means for determining a machine type of the magnetic bearing based on the mean amount of movement and setting control parameters.

3. A method for determining a machine type of a magnetic bearing comprising the steps of:

moving a rolling element supported by a magnetic bearing from a rest position to place on one side of
5 a first radial axis and determining an amount of movement thereof to a movement limit;

then moving said rolling element to place on one side of a second radial axis and determining an amount of movement thereof to a movement limit;

10 then moving said rolling element to place on the other side of the first radial axis and determining an amount of movement thereof to a movement limit;

then moving said rolling element to place on the other side of the second radial axis and determining
15 an amount of movement thereof to a movement limit;

operating a mean amount of movement based on said amounts of movement; and

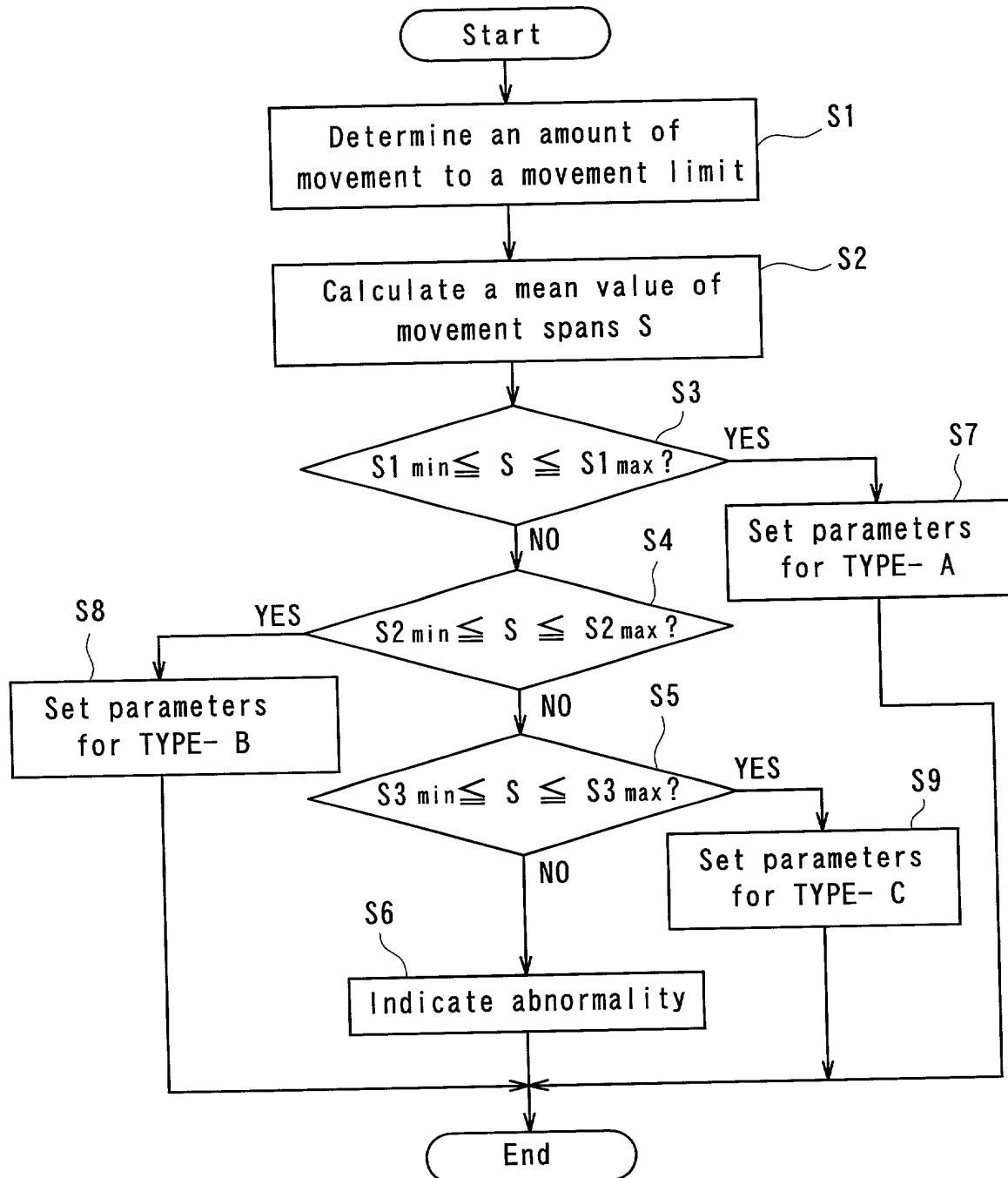
determining a machine type of the magnetic bearing based on said mean amount of movement and setting control
20 parameters.

ABSTRACT

A rolling element in a stationary state as surrounded by magnetic bearings is moved until it abuts against a protective bearing, and thereby a mean value of movement spans S is determined. A machine type is determined based on a fact that the mean value of movement spans varies depending upon the types of machine bodies, and then the setting of control parameters is made. In this manner, a control unit of the magnetic bearing is adapted for multiple types of machine bodies.

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FIG. 1



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FIG. 2

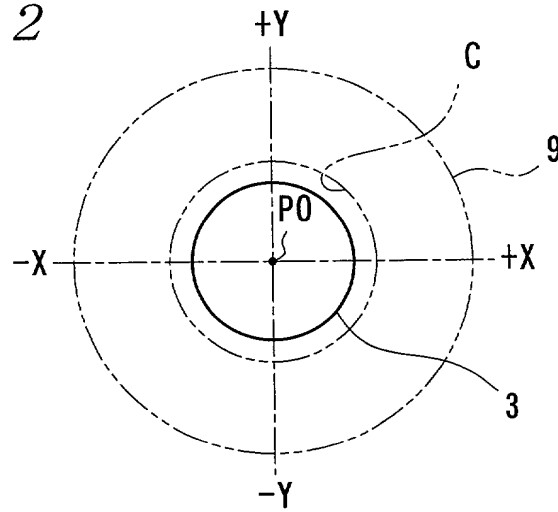


FIG. 3

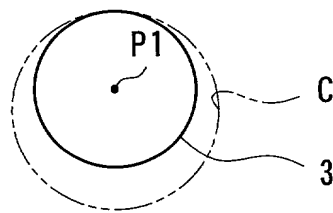


FIG. 4

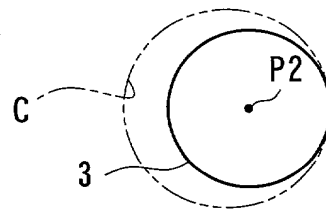


FIG. 5

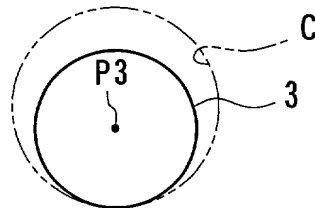


FIG. 6

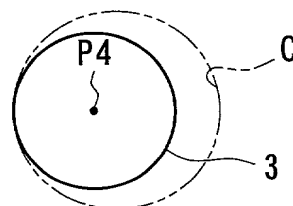


FIG. 7

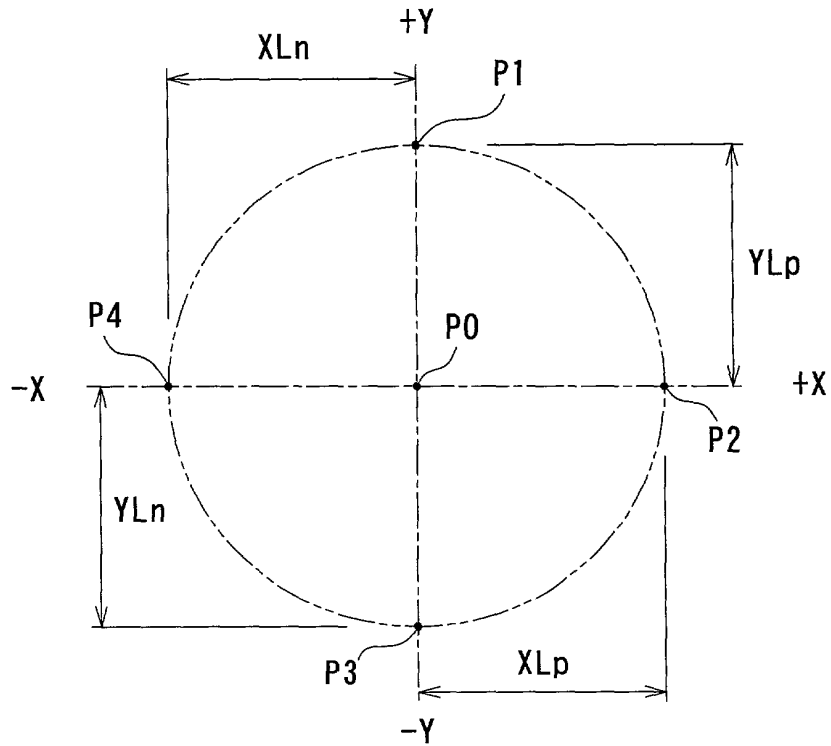
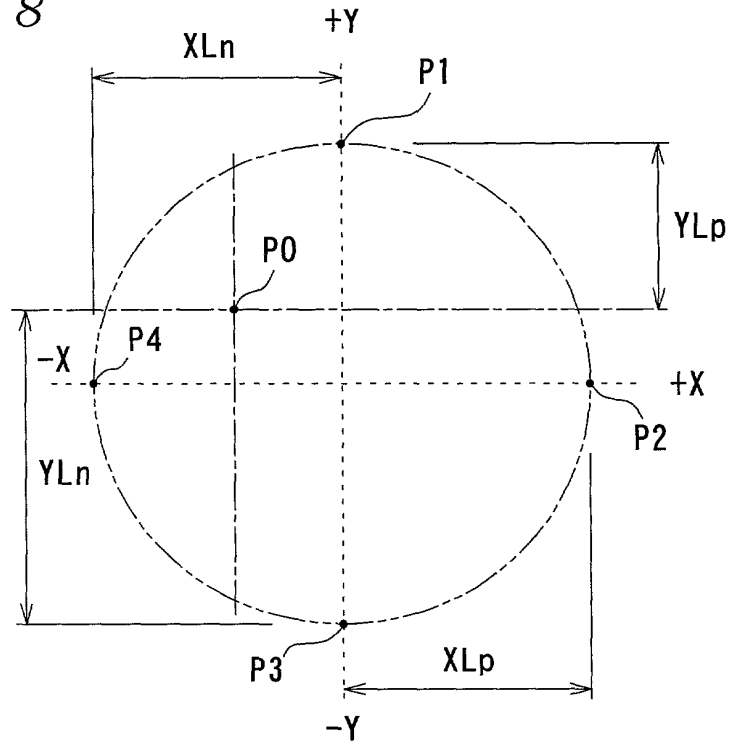
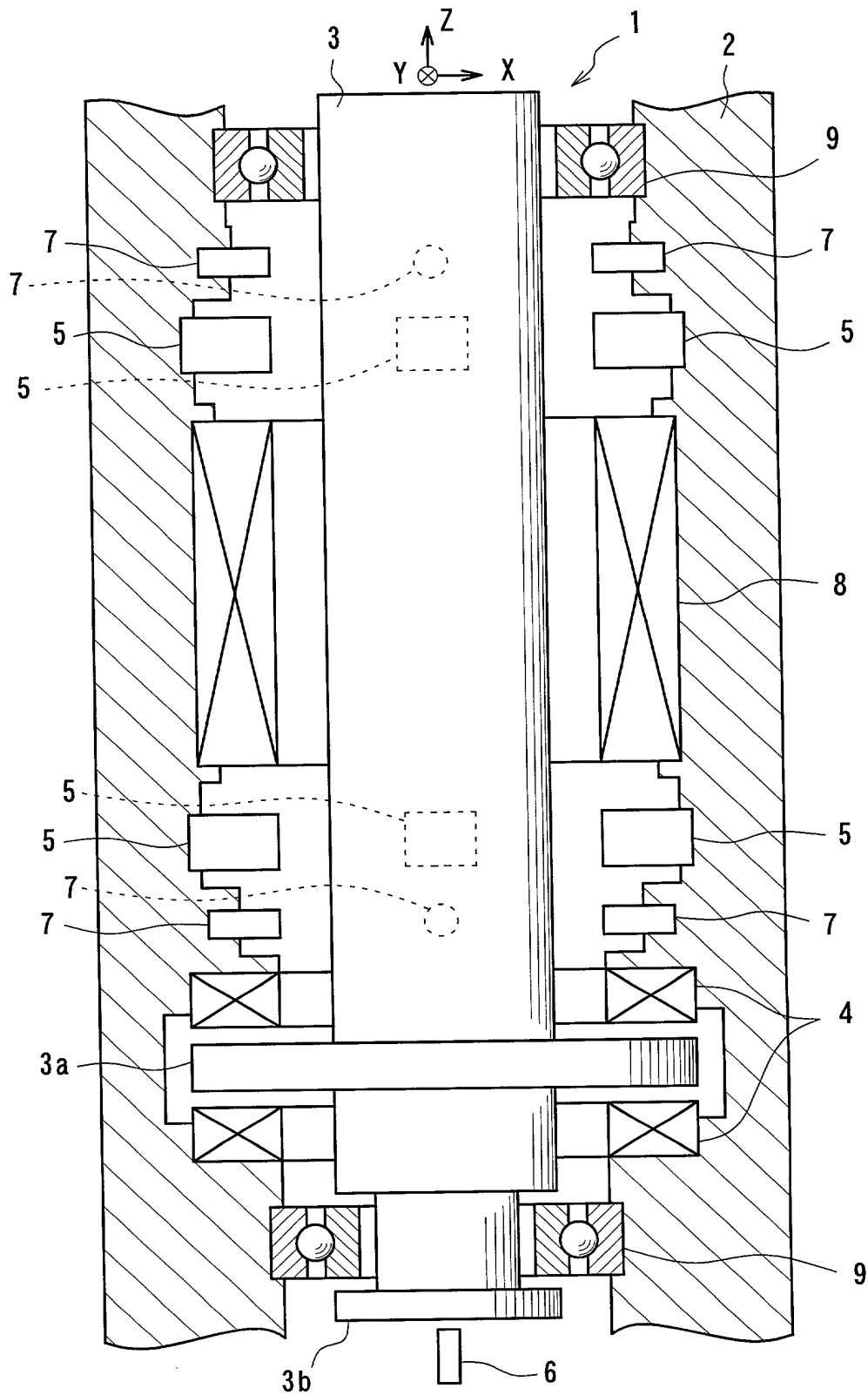


FIG. 8



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FIG. 9



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FIG. 10

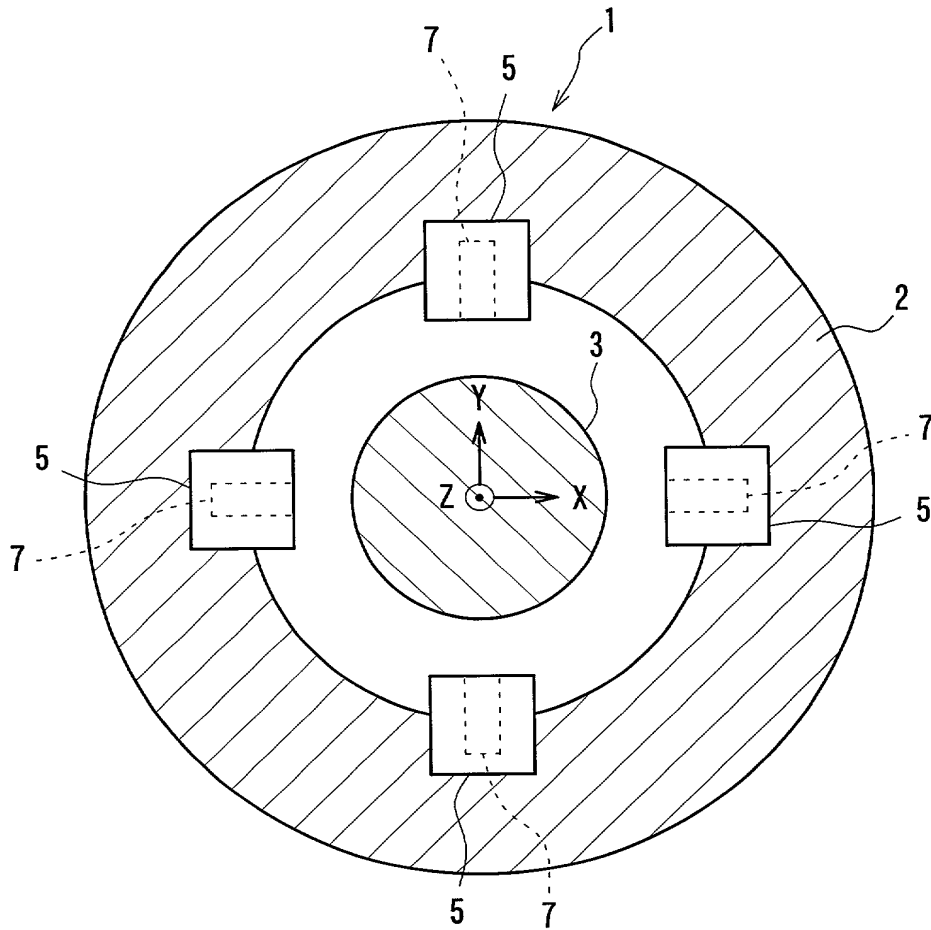


FIG. 11

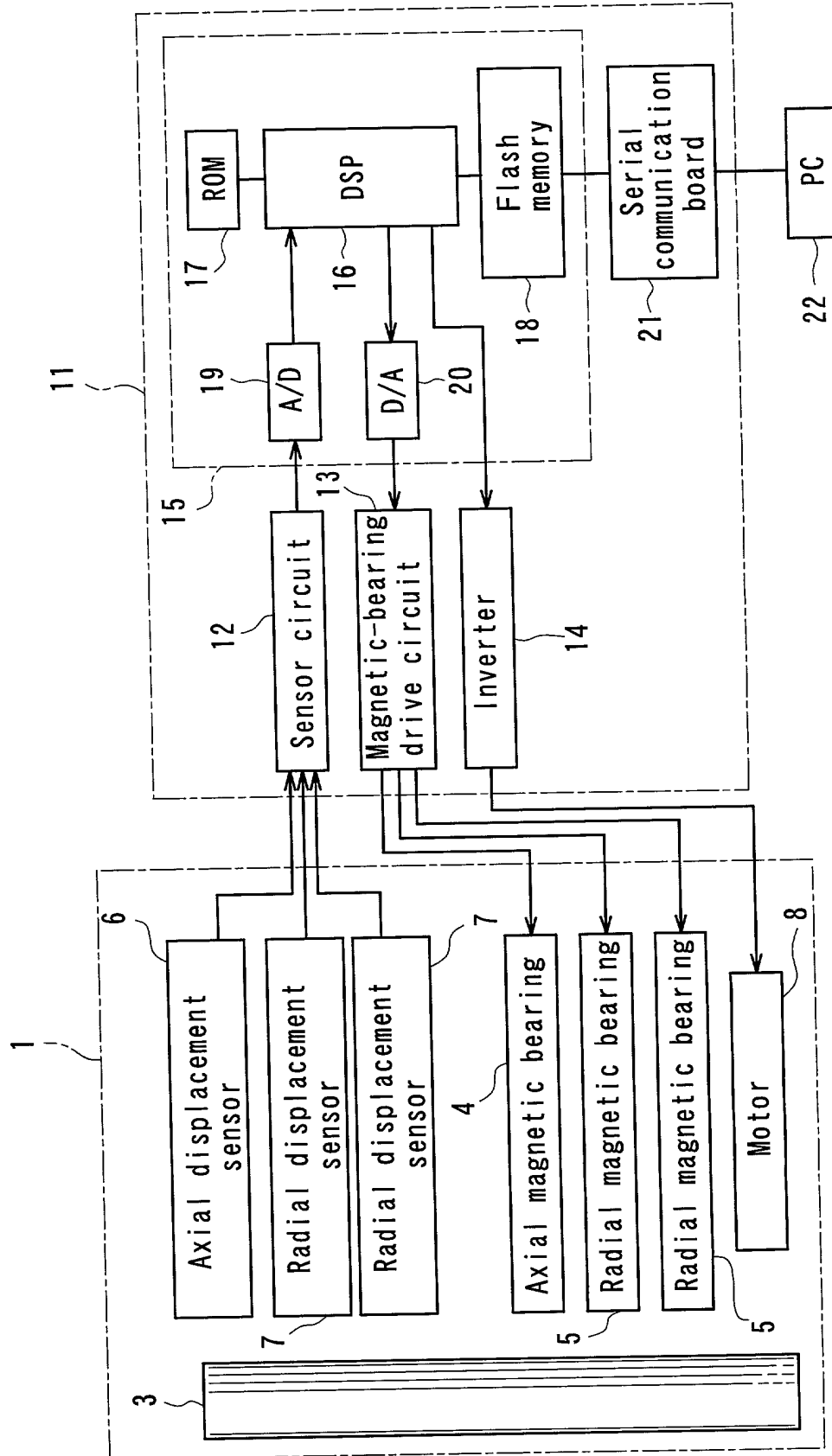


FIG. 12

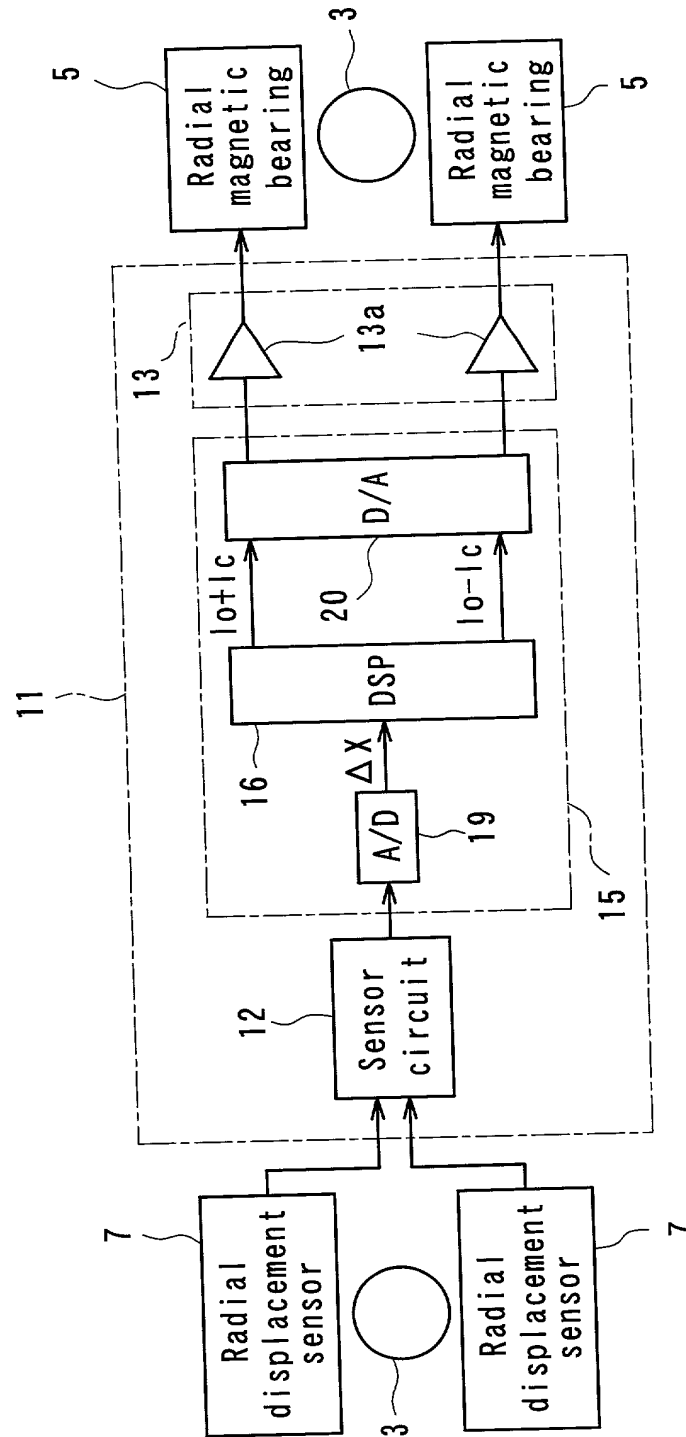
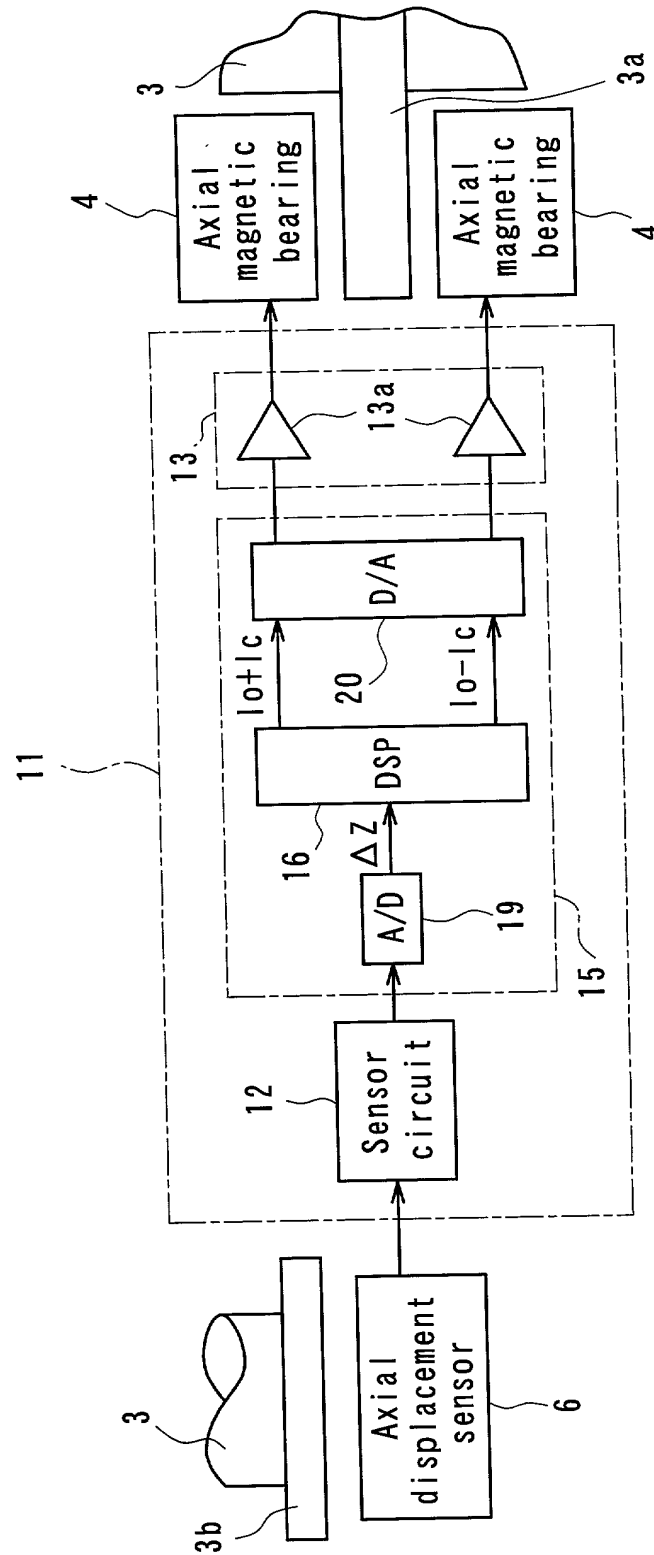


FIG. 13



Declaration and Power of Attorney United States Patent Application

UNITED STATES
Patents and Design Patents
Sole & Joint Inventors
Convention & Non-convention
PCT & Non-PCT
This form cannot be amended, altered
or changed after it is signed.
(For use only for inventors who
understand the English language.)

As a below named inventor, I hereby declare that:
My residence, post office address and citizenship are as stated below next to my name.
I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint
inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on
the invention entitled **CONTROLLABLE MAGNETIC BEARING APPARATUS AND
METHOD FOR DETERMINING A MACHINE TYPE OF A MAGNETIC BEARING**

(check one) ☐ is attached hereto.
☐ was filed as U.S. Application No. _____ on _____ and (if applicable) was amended on _____
☒ was filed as PCT International Application No. PCT/JP00/04781 on July 14, 2000 and (if applicable) was amended under PCT Article 19 on _____.

I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.
I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, §119(a)-(d) or §365(b) of any foreign and PCT application(s) for patent or inventor's certificate, or §365(a) of any PCT international application which designated at least one country other than the United States of America listed in this Declaration. I have also identified below any foreign application for patent or inventor's certificate or PCT international application having a filing date before that of the application(s) on which priority is claimed:

| Foreign/PCT Application No. | Country | Filing Date | Priority Claimed? (yes/no) |
|-----------------------------|---------|---------------|----------------------------|
| 11/200475 | Japan | July 14, 1999 | Yes |

I hereby claim the benefit under Title 35, United States Code, §120 or §365(c) of any United States application and PCT international application designating the United States of America listed in this Declaration and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application or PCT international application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

| U.S. Application No. | Filing Date | Status (patented/pending/abandoned?) |
|----------------------|-------------|--------------------------------------|
| | | |

I hereby claim priority benefits under Title 35 United States Code §119(e) of any U.S. provisional application(s) listed below:

| U.S. Provisional Application No. | Filing Date |
|----------------------------------|-------------|
| | |

I hereby appoint the following attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: Robert G. Weilacher (20,531), Herbert M. Hanegan (25,682), Dale Lischer (28,438), Frederick F. Calvetti (28,557), J. Rodgers Lunsford, III (29,405), Michael A. Makuch (32,263), Dennis C. Rodgers (32,936), William F. Rauchholz (34,701), Michael C. Carrier (42,391), Eric J. Hanson (44,738), Patrick R. Delaney (45,338), Joseph M. Lewinski (46,383) and Brandon S. Boss (46,567).

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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Date: FEB 20, 2001